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PERFORMANCE OF MAIZE (*ZEA MAYS L.*) HYBRIDS FOR EARLY MATURITY TRAITS UNDER PESHAWAR AGRO-CLIMATIC CONDITIONS

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Abstract

Early maturity in maize (*Zea mays L.*) is a desired quality because it facilitates timely crop rotation, allows evasion of terminal stresses, and can sustain productivity within stress-prone areas of Pakistan. The experiment was conducted in spring 2018 at the Malakandair Research Farm, The University of Agriculture, Peshawar, to assess 20 maize hybrids and four check varieties (two local and two imported). The experiment was structured as a randomised complete block design with three replications. Data was recorded on days to 50% tasseling, anthesis, silking, anthesis-silking interval (ASI), plant height, and ear height. Significant differences ($P = 0.01$) were found between hybrids concerning all traits considered, which indicated the coexistence of high genetic variation. Earliness was very high in hybrids PSHW-2321 and PSHW-2324, which had the earliest tasseling stage, anthesis, silking, good ASI values, and moderate plant and ear heights. Highest heritability estimates were found in ASI (61.42), flowering (43 and 50), and lowest in the plant and ear height. The findings showed that PSHW-2321 and PSHW-2324 were better earlier regarding maturity. Such discoveries give leverage to creating stress-tolerant, high-performing maize plants in Pakistan to enable the cultivation of climate-smart agriculture. Hence, it is concluded that PSHW-2321 and PSHW-2324 are early maturing and Pakistan's climate-smart agriculture.

Keywords: Maize hybrids; Early maturity; Anthesis-silking interval; Heritability; Climate resilience

Introduction

Maize (*Zea mays L.*) is a globally vital cereal crop, ranking third in economic importance in Pakistan after wheat and rice. Maize thrives in deep, fertile, well-drained soils with a pH ranging from 7.5 to 8.5. It is characterised by its diploid nature ($2n = 20$) and fibrous root system (Singh *et al.*, 2021). Its monoecious structure and typical phenology with tasseling at around 65 days and maturity by 100–125 days make it highly adaptable to diverse agro-climatic conditions (Bayisa, 2020). Despite its inherent resilience, Wink (2025) notes that Pakistan faces mounting challenges in sustaining maize yields, notably due to shifting climatic patterns, terminal-stage stresses, and pathogen–pest pressure.

Climate change poses a serious and growing threat to maize production in Pakistan. Climate change is projected to reduce maize yields in Pakistan by 27%, mainly due to shortened crop duration, high temperature stress, and increased evapotranspiration affecting pollination and grain filling (Alotaibi, 2023). Another modelling effort in arid and semi-arid zones, including Dahri *et al.* (2024), indicates that increases in maximum temperatures critically impair rainfed maize yields. Maize yields are projected to decrease by 7.4 percent per one Degree rise in global average temperature (Abbas *et al.*, 2023). Hou *et al.* (2021) estimated the yield of maize reduction caused by climate change and found that it decreased by 0.83 t ha⁻¹ and 0.67 t ha⁻¹ with every 1 °C increase in the T_{mean} and T_{min} growing season temperatures, respectively.

Moreover, the growing summer-sown maize in Pakistan has the potential for sustainable maize production under the semiarid and arid climate (Khan *et al.*, 2021). These shifts, combined with increased frequency of heatwaves such as the record-breaking 2022 pre-monsoon heat wave across Pakistan, underline the urgency of adaptation (WMO, 2022).

Furthermore, about 30% of maize land is already planted under hybrids; the remaining 70% is under OPVs, a vast and growing market of maize hybrids in Pakistan. There is a rising demand for maize due to these various uses, which is encouraging farmers to put more money into producing maize. In Pakistan, the prices of maize hybrid seed are also the highest in South Asia, where it costs 7-8 US\$/kg (Ali *et al.*, 2020). However, Kim and Lee (2023) state that terminal drought, heat stress, and climate variability remained constant threats to limit the potential gains.

In light of these challenges, screening and identifying maize hybrids that are early maturing, high-yielding, and resilient to terminal stressors and emerging diseases is critical. This research

hypothesizes that among the tested hybrids, some will demonstrate significant earliness and desirable agronomic traits, making them suitable candidates for cultivation under Pakistan's increasingly erratic climate. Therefore, this study was designed to evaluate and select early-maturing maize hybrids exhibiting superior yield and stress tolerance performance.

Material and Methods

The field experiment was conducted at the Malakandair Research Farm, The University of Agriculture, Peshawar (34°01'N latitude, 71°35'E longitude, 359 m altitude), during the spring season of 2018. A total of 20 maize (*Zea mays* L.) hybrids and four check varieties (two local and two imported) were evaluated. The experimental layout followed a randomised complete block design (RCBD) with three replications. According to Abakemal *et al.* (2024), the design is widely adopted in maize improvement programs to control field variability and enhance precision in hybrid performance assessment. Each subplot consisted of two rows, spaced 0.75 m apart, and standard agronomic practices were applied uniformly across treatments to ensure optimal crop growth. Sowing was performed on February 17, 2018, under irrigated conditions. Data were recorded on key phenological and agronomic traits, including days to 50% tasseling, anthesis, and silking, anthesis–silking interval (ASI), plant height, and ear height. These traits were prioritised as reliable indicators of earliness and yield stability in maize, particularly under environments facing terminal heat and drought stress. Statistical analysis was carried out using the procedure of Gomez and Gomez (1984) for RCBD, and variance analysis was performed through the software “Statistix 10.1.” Heritability estimates and trait associations were also computed following standard quantitative genetics procedures to identify hybrids combining early maturity with desirable agronomic attributes.

Results

Analysis of variance revealed highly significant ($P \leq 0.01$) differences among the tested maize hybrids for all phenological and morphological traits studied, confirming the presence of substantial genetic variability. The mean squares for traits such as days to tasseling, anthesis, silking, anthesis–silking interval (ASI), plant height, and ear height were statistically significant, suggesting that hybrids differed in their ability to express early maturity and desirable agronomic characters (See Table 1).

Days to 50% Tasseling

Table 2 shows that days to 50% tasseling varied between 81 and 85, with a grand mean of 83 days. The earliest tasseling was recorded in hybrids PSHW-8311, PSHW-2321, PSHY-7608, and PSHW-2324 (81 days), while the latest tasseling occurred in PSHY-0408 and Local Check-2 (85 days). Early tasseling implies an advantage in earlier maturity, which is crucial for escaping late-season droughts and heat stress.

Days to 50% Silking

Highly significant differences were observed for days to 50% silking, ranging from 85 to 89 days, with an overall mean of 87 days. Hybrids PSHW-2321 and PSHW-2324 showed the shortest silking duration (85 days), whereas PSHY-0402, PSHY-0404, and PSHY-0407 displayed the longest (89 days) (Table 2).

Days to 50% Anthesis

Days to 50% anthesis ranged between 83 and 88 days. The hybrid PSHW-2321 achieved anthesis the earliest (83 days), while PSHY-0407 required the longest (88 days) (See Table 2). Together with silking, this parameter provides a strong indicator of maturity, and the variation observed demonstrates ample scope for selection.

Anthesis Silking Interval (ASI)

Table 2 depicts that anthesis–silking interval (ASI) ranged from 1 to 4 days. Minimum ASI (1 day) was observed in several hybrids, including PSHW-6636, PSHW-8309, PSHW-2324, PSHW-2325, PSHY-0404, and Local Check-1, whereas maximum ASI (4 days) was recorded in Imported Check-2. Shorter ASI reflects superior pollen–silk synchrony, critical for seed setting and grain yield.

Plant Height (cm)

Plant height also varied significantly among the hybrids, ranging from 145.93 cm (PSHY-0407) to 183.60 cm (Imported Check-2). The grand mean was 167.85 cm (See Table 2). However, taller plants may intercept more light. They are prone to lodging; semi-dwarf genotypes are usually considered more desirable in intensive cultivation systems.

Ear Height (cm)

Ear height ranged from 57.67 cm (PSHY-0404) to 88.60 cm (Local Check-1), with a mean of 77.20 cm (See Table 2). Higher ear placement generally increases the risk of lodging, whereas

excessively low ears may reduce harvesting efficiency. Moderate ear height, therefore, remains a desirable trait.

Heritability

Heritability estimates ranged from moderate to high. ASI showed the highest heritability (61.42%), followed by days to anthesis (50.20%) and days to silking (44.36%), while plant and ear height recorded lower values (24.02% and 22.59%, respectively). This suggests that selection for flowering traits would be more effective than height-related traits in these hybrids (Table 3).

Overall, hybrids PSHW-2321 and PSHW-2324 consistently performed better across early maturity traits, while Imported Check-2, although tallest, displayed the least favourable ASI. These findings point to considerable variation among hybrids that can be exploited for breeding early-maturing, high-performing cultivars.

Table 1: Analysis of variance showing mean squares and coefficients of variation (CV) for flowering traits, plant height, and ear height among 20 maize hybrids. Significant differences ($P \leq 0.05$, $P \leq 0.01$) indicate substantial genetic variability across traits.

Traits	Genotype mean square	Error mean square	Coefficient of variation (%)
<i>Days to tasseling</i>	4.85**	1.41	1.43
<i>Days to silking</i>	5.00**	1.44	1.38
<i>Days to anthesis</i>	4.89**	1.19	1.27
<i>Anthesis-silking interval</i>	1.58**	0.27	36.90
<i>Plant height</i>	214.92*	110.29	6.27
<i>Ear height</i>	147.30*	78.52	11.31

Table 2: Mean performance of 20 maize hybrids for flowering traits (days to 50% tasseling, silking, anthesis, and anthesis–silking interval), plant height, and ear height under field conditions. The range and LSD values indicate genetic variability and significance among hybrids.

S No.	Hybrids	50% Tasseling (days)	50% Silking (days)	50% Anthesis (days)	Anthesis silking Interval	Plant height (cm)	Ear height (cm)
1	PSHW-6636	82	86	85	1	172.20	87.80
2	PSHW-66.5	83	87	85	2	165.33	77.33
3	PSHW-9312	83	86	85	2	169.27	81.60
4	PSHW-8309	82	86	84	1	169.07	76.17
5	PSHW-8311	81	86	85	2	169.53	85.00
6	PSHW-2321	81	85	83	2	168.27	77.40
7	PSHW-2324	81	85	84	1	171.67	75.80
8	PSHW-2325	84	86	84	1	171.93	79.33
9	PSHW-5173	83	87	86	2	170.73	77.93
10	PSHY-0402	84	89	87	2	167.73	80.13
11	PSHY-0404	83	89	87	1	160.40	57.67
12	PSWY-0407	83	89	88	2	145.93	69.93
	PSHY-0408	85	88	86	1	150.87	70.13

13							
14	PSHY-7604	84	86	85	1	164.80	79.87
15	PSHY-7613	83	86	87	1	167.87	78.07
16	PSHY-7608	81	87	85	1	162.13	75.73
17	LOCAL CHECK-1	83	85	85	1	179.80	88.60
18	LOCAL CHECK-2	85	88	86	1	165.20	79.27
19	IMPORTED CHECK-1	84	88	87	1	173.20	81.20
20	IMPORTED CHECK-2	82	87	86	4	183.60	87.40
Range		81-85	85-89	83-88	1-4	145.93- 183.60	57.66-88.60
LSD (0.05)		1.96	1.98	1.80	0.91	17.35	14.64

Table 1: Genetic variance, phenotypic variance, and broad-sense heritability estimates for flowering traits, plant height, and ear height in 20 maize hybrids. The values highlight the extent of genetic control and variability across traits.

Traits	Genetic variance	Phenotypic variance	Broad sense heritability (%)
<i>Days to tasseling</i>	1.1	2.51	43.82
<i>Days to silking</i>	1.18	2.62	44.36

<i>Days to anthesis</i>	1.2	2.39	50.20
<i>Anthesis-silking interval</i>	0.43	0.70	61.42
<i>Plant height</i>	34.87	145.16	24.02
<i>Ear height</i>	22.92	101.44	22.59

Discussion

The evaluation of maize hybrids revealed significant genetic variability, underscoring opportunities for improvement through selection, particularly for earliness and stress escape traits. Earliness, as indicated by days to tasseling, anthesis, and silking, is a valuable trait under Pakistan's climate. Similarly, Becker *et al.* (2023) claimed that terminal drought and heat stress increasingly constrain productivity. The earlier tasseling observed in PSHW-2321 and PSHW-2324 aligns with findings by Ponti and Sannolo (2023), who reported that hybrids differing in phenology could be exploited for specific environments. However, the narrow range (81–85 days) also suggests that while variability exists, incremental gains depend on careful selection of superior genotypes. The observed variation in days to 50% silking (85–89 days) emphasises its utility as a maturity index. Shorter silking duration in PSHW-2321 and PSHW-2324 indicates their potential for double-cropping systems in Pakistan, where timely land vacating is critical. These results agree with Fischer *et al.* (2020), who emphasised that early silking confers an advantage under water-limited conditions. In contrast, the late-silking hybrids (e.g., PSHY-0404) reflect greater exposure to stress during reproductive stages, highlighting their limited suitability in stress-prone regions.

The timing of the occurrence of anthesis also had a similar direction, highlighting its crucial influence in maturity determination. The result that PSHW-2321 attained earlier anthesis accords with those by Nelimor *et al.* (2020), who indicated that early anthesis, coupled with short silking duration, is critical in resilience. The fact that an earlier anthesis is positively correlated to a lower cost of production is also significant, given that it lowers inputs, which is of practical significance to resource-constrained farmers. Anthesis-silking interval (ASI) was a highly differentiating trait

with a heritability value greater than 60%. This shows a high genetic control and agrees with Lima *et al.* (2023) findings that emphasized the significance of ASI in determining drought success in reproduction under less control of gene regulation. The persistently low ASI in PSHW-2324 and Local Check-1 indicates a well-synchronized pollen-silk interaction, which could result in grain formation despite poor circumstances. Conversely, high temperature exacerbated the long ASI characteristic of Imported Check-2, compromising seed set due to pollen desiccation. The differences shown explain why hybrids that have been locally adapted will do better in Pakistani conditions than exotic checks.

While traditionally valued, plant and ear height showed relatively low heritability, suggesting that environmental factors strongly influence their expression. This is consistent with findings by Yang *et al.* (2023), who reported that height traits, though necessary for lodging resistance, are less reliable for direct selection. The tallest hybrid (Imported Check-2) was prone to lodging risk, highlighting that increased biomass does not necessarily translate into a yield advantage. Semi-dwarf types like PSHW-2324 represent a more balanced option, echoing conclusions by Kombat *et al.* (2024) that medium stature ensures stability under high-input conditions. Ear height variation further supports this balance: while Local Check-1 recorded the maximum (88.60 cm), it risks lodging, whereas PSHY-0404, with the lowest (57.67 cm), may compromise mechanical harvest efficiency. Moderately placed ears (e.g., PSHW-2321 with ~77 cm) represent an optimal balance between yield and field management. This agrees with Singh (2021), who stressed that intermediate ear placement is most desirable in hybrid development.

The heritability estimates revealed that traits such as ASI and flowering are essentially under substantial genetic control, whereas environmental factors strongly influence plant and ear height. This partitioning underscores the importance of prioritising early maturity traits in selection programs. Singh *et al.* (2024) confirm that high heritability of flowering parameters makes them reliable targets for breeding early-maturing cultivars, particularly under climate stress scenarios. The overall results suggest that, although tall and vigorous, exotic checks lag in reproductive synchrony and adaptation, whereas local and regionally bred hybrids combine earliness with stress tolerance. This contrast mirrors global experiences where locally bred hybrids outperform introduced materials in stress-prone environments (Prasanna *et al.*, 2020). The consistency of PSHW-2321 and PSHW-2324 across traits demonstrates their potential as parents in hybridisation or as direct commercial releases.

The main strength of this work lies in the in-depth consideration of numerous flowering and morphological characteristics, along with the figures of heritability, which serve as a solid basis to define early-maturing and stress-tolerating maize crosses. Including local and exotic checks also provided meaningful comparisons indicating the superiority of local adaptation materials, validating previous studies by Prasanna et al. (2020) on genotype x environment interactions. The other strength is the focus on anthesis-silking interval (ASI), which is closely tied to reproductive success under drought. Nonetheless, there were a few limitations in the research. The experiment was performed in one place for over one year, limiting the possibility of transferring the results to different agro-ecologies. Meanwhile, data on the farming system integration of yield performance and maturity trait data were incomplete, which would have allowed direct recommendations for breeding targets. Lastly, the limited phenotypic variability in the floral characteristics indicates that further general germplasm testing is required to achieve any long-term breeding gains.

Future research should further assess these evaluations in various environments and cropping seasons to better determine genotype environmental interactions, as Singh et al. (2024) recommended. Combining grain quality and yield attributes with maturity characteristics will result in a holistic selection of the high-yielding hybrids. Marker-assisted selection and genomic prediction are molecular and genomic technologies that can further be used to rapidly identify favorable alleles governing ASI and flowering time (Becker et al., 2023). In addition, participation in breeding and adoption of many early-maturing cultivars specific to localized needs could be boosted by engaging local farmers. The stress-prone areas of Pakistan will be imperative to test the multi-location of these hybrids, like PSHW-2321 and PSHW-2324, to validate their adaptability to future climatic variations.

Conclusion

Significant fluctuations among maize hybrids on flowering and morphological characteristics were observed, with PSHW-2321 and PSHW-2324 showing the highest potential as early maturing ones. Their shorter tasseling, anthesis, silking stages, desirable ASI, and moderate plant and ear height reiterate their flexibility to stress-prone conditions. The high heritability of the traits of maturity depicts the potential of selection, and the lower values of both plant and ear height show that the values are environmentally influenced. These results can serve as the basis for breeding

high-yielding, early-maturing, and stress-tolerant hybrids well-suited to Pakistan's changing climatic conditions.

Author's Contribution

ZU carried out the experiment, collected and analyzed the data, and prepared the initial draft of the manuscript. HR conceptualized and designed the study, provided experimental materials, and critically revised the manuscript for intellectual content.

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